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EFFECTIVENESS OF PERSPECTIVE-TAKING SUPPORT IN A VISUAL LEARNING TASK ON THE CAUSE OF SEASONAL CHANGES: AN EYE-TRACKING APPROACH

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Abstract. *This study examined the effectiveness of incorporating a visual element to support perspective taking in learning about the cause of seasonal changes. Participants were 44 sixth-form pupils who studied materials consisting of illustrations and explanatory texts. In the experimental group, the illustrations included a figure of an observer standing on the Korean Peninsula during summer and winter, whilst the control group viewed the same illustrations without the observer. During the task, eye-tracking devices recorded gaze data, and conceptual understanding was assessed before and after learning. Results showed no significant difference in the proportion of gaze fixation on core areas of the illustrations. However, significant differences emerged in fixation transitions, fixation durations on text, gaze shifts between illustrations and text, and post-test scores of understanding. Eye-movement analyses indicated that the experimental group engaged in cyclic gaze transitions between conceptually related elements of text and illustration, whereas the control group primarily processed text before shifting attention unidirectionally to the illustrations. These findings suggest that perspective-taking elements in visual materials promote qualitatively different cognitive processing strategies and enhance conceptual understanding of astronomical phenomena such as seasonal changes.*

Keywords: *astronomy education, eye-tracking, perspective taking, seasonal change, spatial reasoning*

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Introduction

Among various astronomical concepts, the cause of seasonal changes is particularly difficult for students to understand. Previous studies have reported that many students hold alternative conceptions about this topic, the most prevalent being the idea that the Sun is farther from the Earth in winter than in summer (Atwood & Atwood, 1996; Plummer et al., 2014; Schoon, 1995; Türk et al., 2016; Türk & Kalkan, 2018; Gali, 2021). The scientific explanation for seasonal changes is based on a model in which the Earth orbits the Sun with a tilted rotational axis. Unfortunately, this model is often perceived as disconnected from students' everyday experiences and observations made from the Earth's surface, and students are rarely provided opportunities to link their observations to this model (Plummer & Maynard, 2014). Consequently, students tend to adopt easily accessible alternative conceptions based on their everyday knowledge and experiences. Even after teaching, some students revert to these alternative conceptions, indicating the difficulty of constructing a scientific understanding of the causes of seasons changes through learning (Gali, 2021).

Both the Korean national science curriculum (MOE, 2022) and the Next Generation Science Standards (NGSS Lead States, 2013) suggest a stepwise learning process for understanding seasonal changes. First, students observe the apparent motion of the Sun and the solar altitude from the perspective of an Earth-based observer. Next, they examine the correlation between solar altitude and temperature variations. Finally, students are expected to explain the underlying cause of the observed seasonal patterns. In particular, the final step is designed to use a space-based observer model to explain the seasonal variation in the Sun's meridian altitude, encouraging students to connect their Earth-based observations with spatial reasoning from an external, off-Earth perspective. This stage poses a significant challenge for students, as it requires them to mentally represent Earth's orbit over time and integrate it with the Sun's apparent motion (Testa et al., 2014).

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One of the primary challenges in this reasoning process is related to spatial ability (Plummer et al., 2014; Plummer & Maynard, 2014; Wai et al., 2009). Understanding celestial motion is inherently spatial, and previous studies have consistently reported that students with lower spatial abilities struggle with astronomy concepts (Black, 2005; Plummer et al., 2014; Wilhelm, 2009). Students often find it difficult to shift mentally from an Earth-based perspective and to integrate newly learned solar motion patterns with a space-based model (Gali, 2021; NRC, 2006). The spatial skill essential to this integration is known as perspective-taking ability, which refers to the cognitive capacity to infer what is visible or hidden from another's viewpoint, as well as others' internal states such as knowledge and preferences (Moll & Tomasello, 2006). For effective learning of the cause of seasonal changes, students must be able to visualize the Sun's meridian altitude from an Earth-based perspective while modelling from a space-based perspective (Plummer et al., 2014).

However, in practice, such integration through perspective-taking is often not achieved. Previous studies analysing student explanations or educational designs related to the causes of seasonal changes have indicated a predominant emphasis on the space-based perspective, with insufficient opportunities for students to integrate it with the Earth-based perspective (Hansen et al., 2004; Hsu, 2008; Trumper, 2006). Although students must develop model-based explanations that connect observations with underlying mechanisms, opportunities to bridge both perspectives have been limited and difficult to implement effectively (Plummer & Maynard, 2014).

Another source of difficulty lies in the educational materials used to explain the cause of seasonal changes. In most classrooms, illustrations and textual explanations from textbooks are commonly used (Galano & Testa, 2025; Mason et al., 2017). Representing three-dimensional spatial relationships between the Earth and Sun in two-dimensional illustrations inevitably introduces distortions. The eccentricity of Earth's orbit has often been exaggerated in illustrations (Testa et al., 2014), and to represent temporal progression within a single diagram, the Earth has frequently been depicted at four orbital positions - equinoxes and solstices - simultaneously (Galano et al., 2018). Such representations have been found to cause confusion for students when interpreting the illustrations, ultimately making it difficult for them to construct accurate explanations of the causes of seasonal changes (Lelliott & Rollnick, 2010).

This difficulty in interpreting illustrations leads to additional problems. Scientific explanations typically combine both visuals and text, and when students struggle to understand the visuals, they also have difficulty integrating the two forms of information. Although illustrations and text have been commonly used to enhance understanding of complex scientific concepts (Peterson, 2016), both forms have conveyed mutually dependent information, and constructing a coherent mental model requires integrating them (Ainsworth, 2006; Scheiter et al., 2017). Given the cognitive demands posed by spatially complex and information-rich illustrations of seasonal change, integrating text and visuals may place a heavy cognitive load on learners and increase the likelihood of misinterpretation (Shah & Hoeffner, 2002).

Despite the significance of seasonal change as a core scientific concept, persistent misconceptions, difficulties in perspective-taking, and limitations in educational materials continue to hinder students' conceptual understanding. Prior research has not sufficiently addressed how to effectively support students in integrating Earth-based and space-based perspectives, nor how to reduce the cognitive load imposed by conventional illustrations. This represents a critical problem in science education, as it prevents learners from constructing scientifically accurate explanations of astronomical phenomena. Therefore, it is necessary to examine whether providing explicit perspective-taking supports can overcome these challenges, improve students' visual processing, and enhance their conceptual understanding of seasonal changes.

To address these challenges, this study introduces a support element aimed at facilitating perspective-taking between space-based and Earth-based perspective when learning about the causes of seasonal change using illustrations and text. Prior studies have proposed such direct support strategies to foster the integration of perspectives (Heywood et al., 2013; Plummer, 2012, 2014; Plummer et al., 2011, 2014), which can help reduce students' cognitive load related to perspective-taking (Höffler & Leutner, 2011). Such strategies are expected to enhance students' comprehension of visual representations and improve task performance.

Nevertheless, evaluating the learning outcomes of this perspective-taking support is not straightforward, as various learner-related factors, such as prior knowledge and experience, may influence results. Therefore, this study employed an eye-tracking method, which can provide objective data on learners' cognitive processes. Eye fixation location and duration are closely associated with the mental processes involved in task performance (van Gog et al., 2009), offering empirical evidence regarding the effectiveness of perspective-taking supports.

The research questions guiding this study were as follows:

1. What is the effectiveness of a perspective-taking support element in directing students' visual attention?

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2. To what extent is the support element effective in facilitating transitions in gaze between illustrations and text?
3. How effective is the support element in enhancing conceptual understanding of the cause of seasonal changes?

Research Methodology

Design Overview

This study adopted a true experimental design with a pre-test–post-test control group. A total of 44 sixth-grade students were randomly assigned to either the experimental group (n = 22) or the control group (n = 22). The research was conducted in September–October 2023 during the second semester, when the unit on "Seasonal Changes" is taught in the Korean national science curriculum. The participants were drawn from one elementary school in Gyeonggi Province, South Korea. Although the study was limited to a single school context, the educational sequence and tasks reflected the national curriculum framework.

The research adopted a quantitative approach, combining conceptual understanding assessments with eye-tracking methodology to obtain objective measures of learners' cognitive processes. The theoretical framework draws on perspective-taking theory (Moll & Tomasello, 2006), which highlights the cognitive challenge of coordinating different viewpoints, and cognitive load theory (Chandler & Sweller, 1991), which explains how educational supports can reduce processing demands when learners engage with complex visual representations.

According to the Korean national science curriculum, the unit on "Seasonal Changes" begins with lessons focused on the relationship between solar altitude and temperature variations within a day and across a year, emphasizing Earth-based observations (see Figure 1a). Later in the unit, students explore the causes of seasonal changes by comparing Earth's positions in summer and winter using a space-based observer perspective (see Figure 1b). In this lesson, students learn that differences in the Sun's meridian altitude across seasons arise from Earth's axial tilt as it revolves around the Sun.

Figure 1
Illustrations from the "Seasonal Changes" Unit

(a) Earth-based observer view (b) Space-based observer view

To effectively understand the causes of seasonal changes, students must shift between Earth-based and space-based perspectives. First, they examine a space-based illustration (Figure 1b) to identify the differing angles of sunlight at Earth's summer and winter positions. Then, they use an Earth-based perspective to interpret the Sun's altitude at mid-latitudes, connecting this to earlier lessons in the unit.

This educational sequence encourages students to reason about solar altitude from an Earth-based perspective while viewing a space-based revolution model. This study hypothesised that embedding a perspective-taking support element into the space-based illustration would enhance students' ability to mentally coordinate between space-based and Earth-based perspectives. Providing such a support may facilitate students' inference of seasonal differences in solar altitude and promote the integration of prior educational content. Accordingly, this study examines the effectiveness of a visual perspective-taking element in supporting students' conceptual understanding.

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Participants

Eighty sixth-grade students (39 male, 41 female) from an elementary school in central Korea were initially recruited. All sixth-grade students in the school were invited to participate, and both students and their parents were informed about the non-invasive and safe nature of the eye-tracking procedure. Written informed consent was obtained from students and parents, and the study received approval from the university's Institutional Review Board (IRB).

During data analysis, eye-tracking data from 36 students were excluded because their valid fixation rate fell below the 80% threshold, a commonly applied criterion to ensure the reliability of gaze data (cf. van Gog et al., 2009). As a result, the final dataset comprised 44 students (18 male, 26 female).

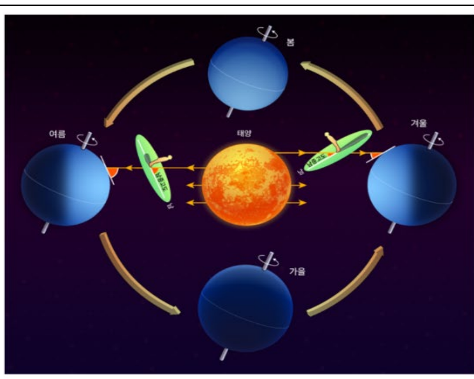
Task and Conceptual Understanding Assessment Development

The learning task was based on the lesson titled "Why Do Seasonal Changes Occur?" from the sixth-grade unit "Seasonal Changes" in the Korean national science curriculum. This task was designed to help students independently explore the cause of seasonal variation in Korea. The illustrations in the learning task were adapted from those commonly found in commercial science textbooks. They visualized the Sun, the Earth's revolution, and the Sun's meridian altitude at mid-latitudes in the Northern Hemisphere during the summer and winter positions of Earth's orbit. To minimize unnecessary cognitive load during the learning process, the eccentricity of Earth's orbital path was reduced, and Earth was represented as a simple blue sphere. Additionally, key visual elements such as Earth's axial tilt, orbital path and direction, and parallel solar rays directed toward Earth were clearly depicted to ensure the illustration was both simplified and conceptually accurate.

For the experimental group, the illustration included a visual element designed to support perspective taking: a human figure placed on Earth at the location of Korea during both summer and winter. A circle representing the ground surface was drawn, with the observer figure positioned at the centre, oriented to indicate front and back. The figure's shadow was cast by parallel solar rays, and one of the rays was extended to connect with the ground, explicitly depicting the angle of incidence between the sunlight and the surface. In contrast, the control group's illustration did not include the human figure. Illustrations were professionally created and revised three times.

The explanatory text was extracted from the most widely used science textbook currently used in schools. In the task layout, the illustration was positioned on the left side and the text on the right. The finalized versions of the experimental and control tasks are shown in Figure 2. To ensure content validity, three experts in Earth science education with experience in eye-tracking research reviewed the materials. The task was revised based on their feedback across two rounds of review, and the final Item-Level Content Validity Index (I-CVI) score was 1.0. A pilot test with six sixth-grade students (three per group) confirmed the feasibility of the task.

Figure 2
Learning Tasks for Experimental and Control Groups



계절의 변화는 지구의 자전축이 기울어진 채 태양 주위를 공전하기 때문에 생깁니다. 지구의 자전축이 기울어진 채 태양 주위를 공전하면 지구의 위치에 따라 태양의 남중고도가 달라지고, 단위 면적의 지표면에 도달하는 태양에너지의 양이 달라져 계절이 변합니다.

지구의 자전축이 기울어져 있지 않거나 지구가 태양 주위를 공전하지 않는다면 계절의 변화가 생기지 않습니다.

Experimental task

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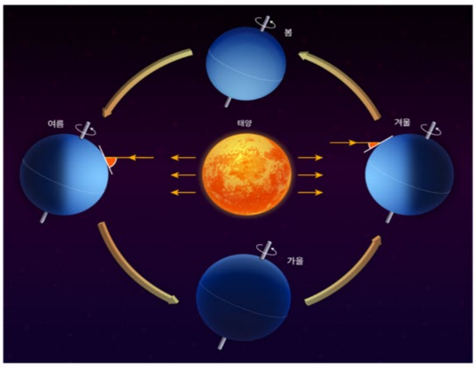

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Control task

Note. The original Korean text in the figure has been translated into English in the Appendix.

To assess students' conceptual understanding, a pre- and post-assessment was developed, in which students were asked to explain the cause of seasonal changes using both drawings and written descriptions. The assessment consisted of a single A4 page and was administered before and after the learning task.

Data Collection

The learning task was implemented during the final lesson titled "Why Do Seasonal Changes Occur?" within the "Seasonal Changes" unit. In this session, students engaged in self-directed learning to construct their understanding of the concept using the provided materials. Accordingly, data collection had to be scheduled in alignment with the educational sequence of each participating class. The unit "Seasonal Changes" is typically taught in the second semester, around October. Accordingly, the pre-test was administered in September 2023 before the unit began. After the regular lessons for the unit, the learning task and post-test were conducted during the designated lesson. An overview of the data collection process is shown in Table 1.

Table 1
Overview of the Data Collection Process

Stage	Method	Content
Pre-test	Conceptual understanding assessment	Expressing the cause of seasonal changes through writing and drawings
Preparatory lessons	Regular classroom lessons	Making a 3D model of the four seasons
		Measuring solar altitude, shadow length, and temperature throughout the day
		Exploring the relationship between solar altitude, shadow length, and temperature during the day
		Investigating the relationship between seasonal variation in solar altitude, day length, and temperature
		Exploring why temperature changes with solar altitude
Main experiment	Eye-tracking during Task performance	Why do seasonal changes occur?
Post-test	Conceptual understanding assessment	Expressing the cause of seasonal changes through writing and drawings

Prior to the unit lessons, a printed conceptual understanding assessment was administered as a pre-test. Students were given approximately 10 minutes to freely express their understanding of the cause of seasonal changes using both drawings and written explanations. During the unit, regular lessons were carried out through

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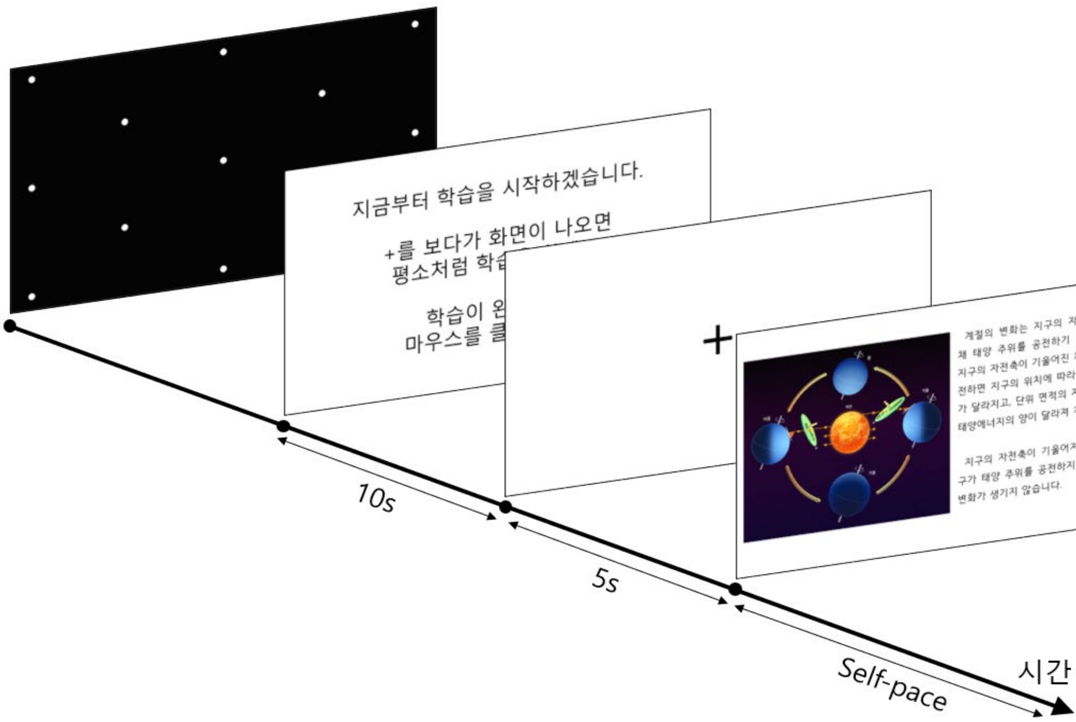
five lessons. To control for teacher-related variables, a single science teacher conducted all five lessons using the same teaching content and methods across multiple classes.

The experiment was conducted individually in a quiet, isolated room within the school, where external light and noise were minimized. To help participants concentrate, partitions were placed on both sides of the desk, and height-adjustable chairs were provided. Students were randomly assigned to either the experimental or control group using a random number table, regardless of the order in which they participated. Each participant engaged in a self-directed learning task displayed on a monitor while their eye movements were recorded using a Tobii X2-60 eye tracker mounted on the bottom of a 17-inch monitor. The eye-tracking task paradigm used in this experiment is illustrated in Figure 3.

Figure 3
Eye-tracking Task Paradigm



Upon seating, students received a brief explanation and completed a calibration process. The task sequence included a 10-second instructional screen followed by a 5-second display of a central fixation cross ("+") before the learning task appeared. There was no time limit for completing the task; participants were asked to click the mouse upon finishing. On average, task completion took approximately 5 minutes. After completing the learning task, students took a post-test using the same conceptual understanding assessment as in the pre-test, which asked them to explain the cause of seasonal changes using both drawings and written explanations.

Data Analysis

Data analysis was conducted using Tobii Pro Lab, with the minimum fixation duration set to 100 ms. Based on the research questions, the analysis was divided into three parts: visual attention to the learning task, integration between illustrations and text, and conceptual understanding.

Visual attention was examined using three specific approaches. The first analysis investigated group differences in gaze attention to key areas of the illustration. These key areas included Earth's positions during summer and winter, the Sun, and the Sun's meridian altitude depicted along Earth's orbital path. To accurately understand the concept using the illustration, students needed to identify and compare the relative position of the Sun and the difference in solar altitude between summer and winter.

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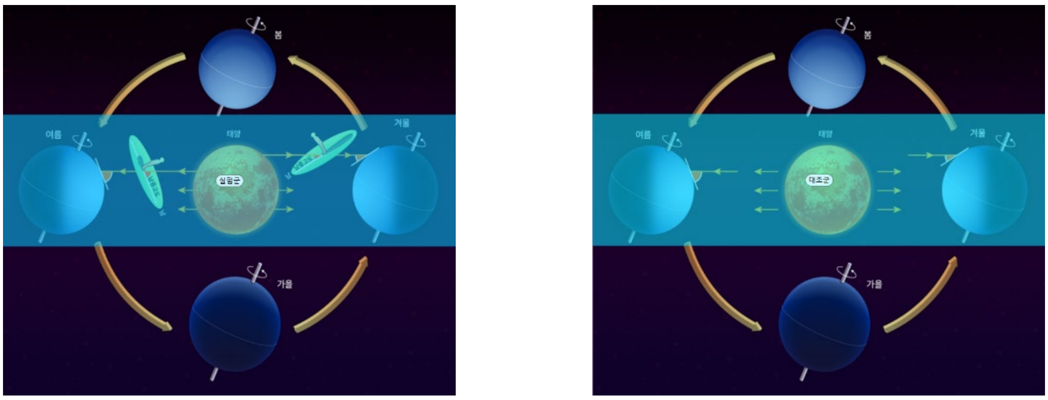
Accordingly, we examined whether the presence of a visual perspective-taking support element influenced students' gaze attention to these key parts. For this purpose, AOIs were defined around the summer and winter positions of the Earth and the Sun (see Figure 4). The proportion of total visit duration within each AOI relative to the overall task duration was used as a measure of visual attention to the key areas. Group differences were statistically analysed using the Mann-Whitney *U* test.

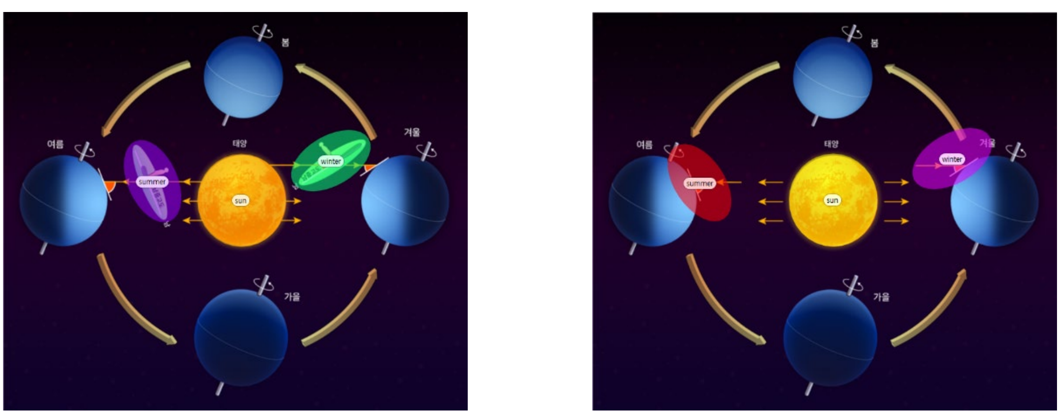
Figure 4
AOIs for Key Illustration Areas in Experimental and Control Groups



AOIs for the experimental task AOIs for the control task

Second, group differences in the number of gaze transitions between the Sun and the indicators of solar meridian altitude for summer and winter in the illustration were analysed. To understand the concept through the illustration, students needed to alternate their attention between the Sun's position and the angles formed by sunlight and the ground at Earth's summer and winter positions—an essential process that is revealed through eye movement behaviour. For this purpose, three distinct AOIs were defined: the Sun, the solar meridian altitude at the summer position, and the solar meridian altitude at the winter position (Figure 5). To ensure valid comparisons, the AOI sizes were kept identical across the experimental and control groups. All fixation coordinates were extracted in chronological order, and a gaze transition was counted when a fixation moved sequentially from one AOI to another. Consecutive fixations within the same AOI were excluded from the count. The total number of these gaze transitions between AOIs was statistically compared between the two groups using the Mann-Whitney *U* test.

Figure 5
AOIs for Analysing Gaze Transition Frequency



AOIs for the experimental task AOIs for the control task

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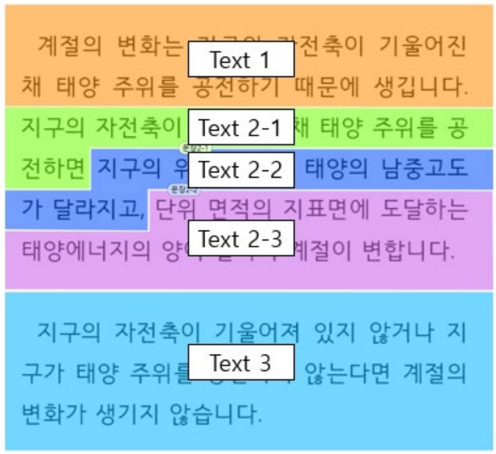
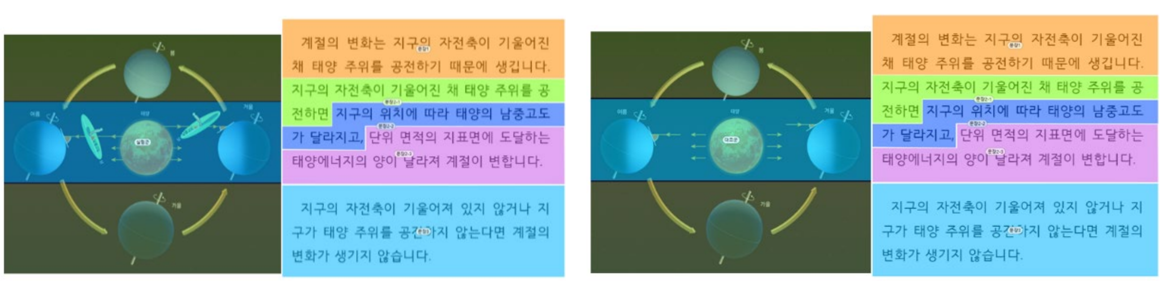
Third, we analysed group differences in the duration of visual attention allocated to each sentence in the explanatory text. To conduct this analysis, each sentence was designated as a separate AOI (Figure 6), and the total fixation duration within each AOI was calculated. Statistical comparisons between groups were performed using the Mann-Whitney *U* test.

Figure 6
AOIs for Text-based Visual Attention Analysis



To examine the patterns of integration between illustrations and text, we employed Lag Sequential Analysis (LSA), a method introduced by Bakeman and Gottman (1997). LSA allows researchers to analyse gaze transition sequences between AOIs and to calculate the probabilistic likelihood of transitioning from one fixation area to another based on the immediately preceding gaze point (Lee, 2005). This method enables researchers to infer students' reading strategies when engaging with illustrated science texts (Bakeman & Gottman, 1997; Jian, 2016). For the analysis, AOIs were defined as shown in Figure 7. Following the LSA algorithm, the analysis focused on the number of transitions between different AOIs, excluding repeated fixations within the same AOI (Bakeman & Gottman, 1997; Hsu et al., 2019). The LSA procedure followed the steps outlined by Hsu et al. (2019), and an extended version of the Data Analysis Tool ver. 1.7, originally developed by Jeong (2003), was used. Based on the frequency of gaze transitions between AOIs, a Z-score matrix was constructed. Transitions with Z-scores equal to or greater than 1.96 were considered statistically significant, and their transition probabilities were extracted. Finally, a transition diagram was created to visually represent significant AOI-to-AOI transitions, which was then used to interpret students' reading strategies.

Figure 7
AOIs for Illustration–text Transition Analysis



AOIs for the experimental task　　AOIs for the control task

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In addition, students' conceptual understanding before and after the task was analysed using the concept assessment instrument, and comparisons between groups were conducted. For the analysis, eight core conceptual elements were extracted from the coding scheme developed by Testa et al. (2023) for evaluating students' drawings related to seasonal changes. Based on these elements, evaluation criteria and items were established, as shown in Table 2. Each item was scored as 1 point if the corresponding concept was present, resulting in a maximum possible score of 8. To ensure the reliability of the analysis, inter-rater agreement was calculated among four graduate students majoring in science education. The average Cohen's Kappa coefficient was .85, indicating a satisfactory level of coding consistency.

Table 2
Evaluation Criteria and Items for Pre- and Post-Test of Conceptual Understanding

Conceptual Category	Evaluation Item
Axial Tilt	Drawing or mentioning of the axial tilt
	Correct representation or explanation of the axial tilt
Solar Altitude & Energy	Drawing or explanation of changes in solar altitude or solar energy
	Accurate representation or explanation of these changes
Revolution	Drawing or mentioning of Earth's revolution
	Depiction of a Sun-centred model or description of the Earth's revolution around the Sun
	Drawing or explanation of Earth's orbit
	Inclusion or explanation of the counterclockwise orbital direction

Research Results

Effects of Perspective-Taking Support on Students' Visual Attention

The first analysis of visual attention examined group differences in attention to the core components of the illustration-specifically, the positions of Earth in summer and winter and the Sun. A Mann-Whitney *U* test was conducted to determine whether the proportion of visual attention directed to these key areas differed between the groups. As shown in Table 3, no statistically significant difference was found. This result suggests that the presence or absence of the perspective-taking support element had little effect on students' allocation of attention to the core parts of the illustration.

Table 3
Mann-Whitney U Test Results for Visual Attention to Key Illustration Areas

Group	N	M	Σr	Z
Experimental group	22	24.09	530.00	-.822
Control group	22	20.91	460.00	
Total	44			

The second analysis examined group differences in the number of gaze transitions between the Sun and the indicators of solar meridian altitude for summer and winter. The results of the Mann-Whitney *U* test are presented in Table 4. The experimental group exhibited a significantly higher number of gaze transitions than the control group at the .01 level. This suggests that participants in the experimental group more frequently shifted their gaze between the Sun and the altitude indicators, indicating a more active integration of key visual components necessary for understanding the concept. This finding provides evidence that the visual perspective-taking support element facilitated more effective processing of the illustration. However, it is also possible that this effect was partially influenced by the spatial proximity of the Sun and the solar altitude indicators in the experimental

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illustration, as well as the visual continuity created by connecting solar rays, which may have guided students' gaze more fluidly across related elements.

Table 4
Mann-Whitney U Test Results for Number of Gaze Transitions

Group	*N*	*M*	Σ*r*	*Z*
Experimental group	22	27.14	597.00	-2.767**
Control group	22	17.86	393.00	
Total	44			

** $p<.01$

The third analysis examined group differences in the total fixation duration on each sentence of the explanatory text. A Mann-Whitney *U* test was conducted for each sentence, and the results are presented in Table 5. A statistically significant difference at the .05 level was found for Text 2-3, with the experimental group spending less time fixating on this sentence than the control group. The sentence reads: "The amount of solar energy reaching a unit area of Earth's surface changes, which causes the seasonal changes." This suggests that the perspective-taking support element may have facilitated more efficient processing and comprehension of this particular concept. No significant differences were observed for the other sentences.

Table 5
Mann-Whitney U Test Results for Fixation Duration on Text Sentences

Category	Group	*N*	*M*	Σ*r*	*Z*
Text 1	Experimental group	22	20.73	456.00	-.428
	Control group	20	22.35	447.00	
	Total	44			
Text 2-1	Experimental group	22	21.89	481.50	-.214
	Control group	20	21.08	421.50	
	Total	44			
Text 2-2	Experimental group	22	21.89	481.50	-.317
	Control group	22	23.11	508.50	
	Total	44			
Text 2-3	Experimental group	22	18.20	400.50	-2.218*
	Control group	22	26.80	589.50	
	Total	44			
Text 3	Experimental group	22	18.19	382.00	-1.944
	Control group	22	25.64	564.00	
	Total	44			

* $p<.05$

Effects of Perspective-Taking Support on Illustration–Text Gaze Transition Patterns

Lag Sequential Analysis (LSA) was conducted to examine gaze transition patterns between illustration and text elements, enabling the identification of reading strategies influenced by the presence or absence of the perspective-taking support element. Tables 6 and 7 show the *Z*-score matrices for the experimental and control

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groups, respectively. These matrices statistically evaluate whether transitions between AOIs occurred by chance or represent meaningful behavioural patterns. A Z-score greater than 1.96 indicates a statistically significant transition at the $p < .05$ level, and such cells are shaded in the tables. For each significant cell ($Z > 1.96$), the corresponding transition probability is also shown in parentheses. This probability, ranging from 0 to 1, reflects the likelihood that a gaze shifts from one AOI to another, with higher values indicating stronger transition tendencies.

Table 6
Z-score Matrix and Transition Probabilities for Experimental Group

	Text 1	Text 2-1	Text 2-2	Text 2-3	Text 3	Key Area (Red Box)	Non-Key Areas
Text 1		7.89(.42)	-3.38	-2.45	-3.49	-2.87	-1.41
Text 2-1	3.77(.28)		6.49(.34)	-1.59	-3.62	0.32	-1.01
Text 2-2	-2.40	5.58(.36)		8.07(.34)	-1.75	-0.40	-1.19
Text 2-3	-1.80	-3.27	1.73		8.45(.39)	1.37	1.32
Text 3	-1.67	-2.87	-1.78	1.65		2.43(.20)	-0.45
Key Area (Red Box)	0.23	-1.82	3.98(.29)	-0.68	-0.68		6.90(.19)
Non-Key Areas	-0.23	-1.87	-1.66	-1.85	0.68	6.85(.50)	

Note. Only significant values shown in shaded cells where $Z > 1.96$

Table 7
Z-score Matrix and Transition Probabilities for Control Group

	Text1	Text2-1	Text2-2	Text2-3	Text3	Key Area (Red Box)	Non-Key Areas
Text1		11.11(.52)	-2.36	-3.72	-1.48	-1.99	-1.3
Text2-1	4.19(.26)		7.92(.42)	-2.46	-3.61	-1.70	-1.39
Text2-2	-1.62	1.16		8.26(.45)	-3.73	0.34	-2.17
Text2-3	-3.31	-3.81	3.32(.25)		9.34(.42)	0.58	-1.12
Text3	-0.77	-2.99	-2.93	2.72(.28)		2.44(.14)	3.73(.10)
Key Area (Red Box)	1.84	0.00	-0.67	-0.37	1.12		5.22(.16)
Non-Key Areas	-0.81	-1.50	-1.63	-1.32	1.34	6.93(.42)	

Note. Only significant values shown in shaded cells where $Z > 1.96$.

Figures 9 and 10 visually represent the statistically significant transition probabilities extracted from Tables 5 and 6, respectively. Arrows indicate significant gaze transitions, and the accompanying numbers represent the corresponding transition probabilities. Figure 8 shows the gaze transition pattern of the experimental group. In this group, frequent transitions were observed between the key components of the illustration (highlighted in red in Figure 8) and core textual elements, particularly Text 2-2 ("The solar altitude varies depending on Earth's position"), Text 2-3 ("The amount of solar energy received per unit area changes, which causes seasonal change"), and Text 3 ("If Earth's axis were not tilted or if Earth did not revolve around the Sun, there would be no seasonal change"). These cyclic gaze patterns suggest that the visual perspective-taking support effectively encouraged integration between the critical illustration and relevant text components. The absence of regressions to earlier sentences indicates that students did not struggle with understanding the conceptual content.

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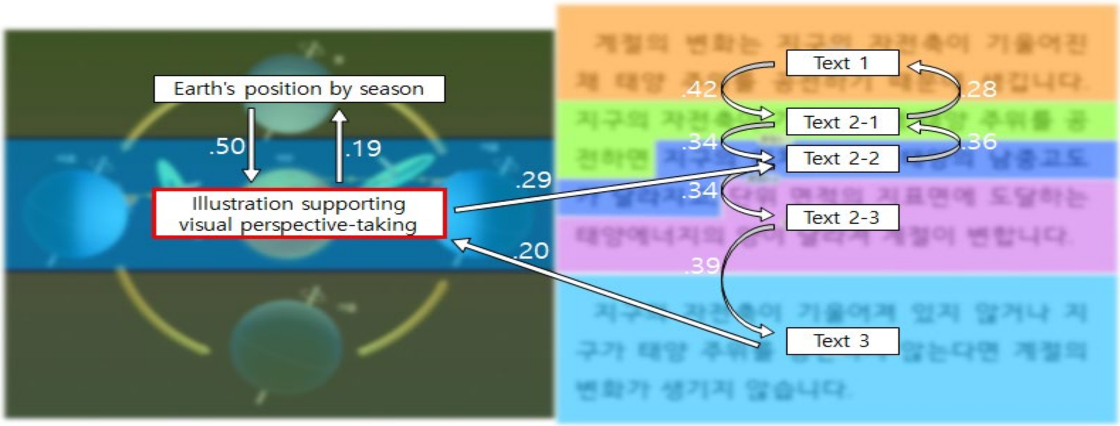
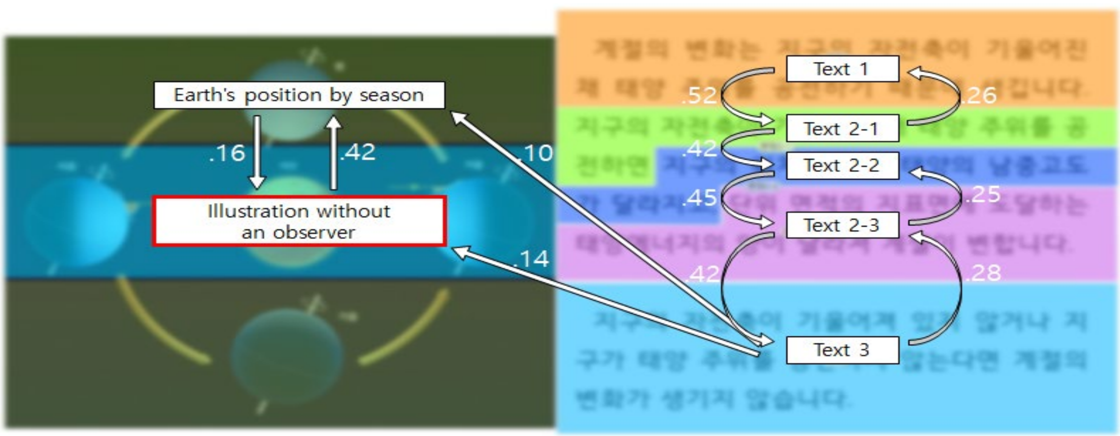
Figure 8
Gaze Transition Pattern - Experimental Group



In contrast, Figure 9 presents the gaze transition pattern of the control group, showing a clear tendency to move to the illustration only after reading the entire text. The transitions from the final text segment to the illustration were unidirectional, with low transition probabilities (.10 and .14), indicating a lack of integrative cognitive processing between text and illustration. These findings suggest that the control group processed the task less efficiently, treating the text and the illustration as separate components. Additionally, transitions toward the key parts of the illustration (highlighted in red in Figure 9) were less frequent compared to the experimental group. More frequent regressions to earlier sentences in the main text were also observed, suggesting that students in the control group experienced greater difficulty in understanding the conceptual explanations.

Figure 9
Gaze Transition Pattern - Control Group



Effects of Perspective-Taking Support on Conceptual Understanding

Pre- and post-tests of conceptual understanding were administered to both the experimental and control groups. Independent samples t-tests were conducted to examine group differences in scores (Table 8). The results revealed no significant difference in the pre-test scores, suggesting that the two groups were comparable in their initial level of conceptual understanding. However, a statistically significant difference was found in the post-test scores at the .01 level, with the experimental group scoring higher than the control group. These findings suggest that the learning task incorporating the visual perspective-taking support element was more effective in enhancing students' conceptual understanding.

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Table 8
Independent Samples T-Test Results for Conceptual Understanding Scores

Test	Group	*n*	*M*	*SD*	*t*
pretest	Experimental group	22	7.59	5.90	.025
	Control group	22	7.55	5.96	
posttest	Experimental group	22	20.00	9.53	3.38**
	Control group	22	11.86	6.04	

** $p<.01$

Discussion

This study examined the effectiveness of incorporating a perspective-taking support element to help elementary school students more effectively process a learning task about the causes of seasonal changes. Eye-tracking methodology was employed to examine how the support influenced students' visual attention, gaze behaviour, and conceptual understanding. The results showed no significant group differences in the proportion of visual attention directed to the key parts of the illustration, regardless of the presence of the support element. However, significant differences were observed in other aspects: the number of gaze transitions, total fixation durations on specific text segments, gaze transition patterns between text and illustration, and post-task conceptual understanding scores. These findings suggest that the perspective-taking support did not affect how attention was distributed across visual elements but rather influenced the qualitative aspects of cognitive processing—such as how students interpreted and integrated the information presented. In other words, the perspective-taking support influenced how students processed and connected the visual and textual information, leading to deeper conceptual understanding.

Specifically, a significant difference was found in the number of gaze transitions between the Sun and the solar meridian altitude indicators depending on the presence of the perspective-taking support. To accurately grasp the seasonal differences in solar altitude using the illustration, students need to actively examine the angles formed between the sunlight and the ground. Gaze transitions between these key elements are considered indicators of successful information processing (O'Keefe et al., 2014). Although the two groups were presented with similar visual information, the experimental group exhibited more frequent transitions, suggesting that the perspective-taking support element promoted more effective processing of the illustration.

Furthermore, a significant difference was found in the fixation duration for Text 2-3, with the experimental group showing a shorter fixation time. This suggests that less cognitive effort was required to understand this sentence, likely due to the contextual framework already established through Text 2-1 and Text 2-2, which explained how Earth's revolution causes variations in solar altitude. Text 2-3 builds on this by stating that seasonal changes occur due to differences in the amount of solar energy reaching Earth's surface. Generally, increased cognitive load is associated with longer fixation durations (Ozcelik et al., 2010; Rayner, 1998). The shorter fixation duration in the experimental group implies that the sentence was more readily integrated into their existing mental model, indicating that the perspective-taking support element may have facilitated more efficient text processing.

One of the most salient findings of this study was the clear difference in the integration patterns between text and illustration depending on the presence of the perspective-taking support element. For students to construct a sophisticated mental model of the content, it is essential that they integrate textual and visual information into a coherent representation (Ainsworth, 2006; Scheiter et al., 2017). Such integration requires learners to identify and connect related elements across text and illustration while operating within the limits of cognitive capacity (Schnotz et al., 2014; Scheiter et al., 2017). The gaze transition patterns captured through eye-tracking revealed how each group engaged in this integrative learning process.

The control group exhibited a sequential processing pattern in which students tended to process the text in its entirety before attending to the illustration. This pattern is commonly observed among novice learners (Hegarty & Just, 1993; Jian & Ko, 2017; Johnson & Mayer, 2012; Schmidt-Weigand et al., 2010; Schnotz et al., 2014). In such cases, learners typically allocate their initial attention to the text to form a preliminary understanding, and then attempt to locate and integrate relevant elements from the illustration based on that foundation (Schmidt-Weigand et al., 2010; Schnotz et al., 2014). However, this approach may result in either minimal attention to relevant parts of

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the illustration or superficial processing, making it difficult to construct a fully integrated mental model (Hannus & Hyönä, 1999; Schnotz et al., 2014). Additionally, the control group exhibited notable regression to earlier sentences, a pattern of text-centred gaze behaviour that suggests an attempt to construct an initial understanding solely from the text before engaging with the illustration (Scheiter & Eitel, 2017). This regressive pattern implies difficulties in forming integrated representations using the text alone (Goldman & Saul, 1990), highlighting that deep conceptual processing is unlikely to occur without meaningful reference to the accompanying visuals (Jian, 2016; Jian & Ko, 2017).

In contrast, the experimental group demonstrated a cyclical pattern of attention between the text and the illustration, suggesting a gradual construction of a coherent mental model through integrative processing. Given that the task presented information in both textual and visual formats, it constituted a cognitively demanding stimulus. To process this effectively, students had to retain parts of the textual content in their working memory (Chandler & Sweller, 1991) while concurrently identifying and integrating related visual elements from the illustration (Kaplan & Erden, 2008). This process requires substantial cognitive effort, but the mutual reinforcement between text and illustration helps deepen comprehension (Seufert, 2019). Accordingly, repeated transitions between text and illustration facilitate the construction of a more consistent and coherent mental representation (Jian, 2016; Jian & Ko, 2017; Schnotz et al., 2014; Schüler, 2017).

In addition, although there was no significant difference in the pre-test scores of conceptual understanding between the experimental and control groups, the post-test revealed a statistically significant gap, indicating that the two groups processed the task in qualitatively different ways. Based on this result, it can be inferred that the presence of the perspective-taking support element led to a shift in students' information processing strategies during the task of learning about the causes of seasonal change. To interpret the illustration explaining seasonal change, students are required to make an inferential shift from the space-based model of Earth's revolution to an Earth-based observer's perspective on the Sun's meridian altitude. This shift is cognitively demanding, especially when students are not given sufficient time or support to make the transition (Plummer & Maynard, 2014). In this respect, the perspective-taking support element served as a cognitive scaffolding tool. It went beyond a decorative role by embedding the viewpoint of an observer into the illustration, helping students reconstruct their understanding from the Earth-based frame they had encountered in earlier lessons. This allowed them to more effectively interpret the visual information and integrate it with prior knowledge.

Additionally, the perspective-taking support appears to have functioned as a perceptual cue that facilitated the integration of text and illustration. Successful integration requires learners to appropriately map related elements across different representations (Schnotz et al., 2014). As seen in the experimental group's gaze transition patterns (Figure 9), the perspective-taking support element was visually salient within the illustration, effectively capturing students' attention. Such perceptually prominent features tend to draw visual attention easily (Underwood & Foulsham, 2006) and, in this context, highlighted the key concept of seasonal differences in solar meridian altitude. By doing so, the support likely promoted more effective connections with the relevant textual information.

However, this study has a limitation in that it could not directly determine whether students were guided by the perspective-taking support element to adopt an Earth-based viewpoint from a mid-latitude position and represent solar meridian altitude accordingly. To obtain explicit evidence of students' perspective-taking, verbal data such as think-aloud protocols would be necessary. However, elementary school students often face difficulties in verbalising their cognitive processes (van Someren et al., 1994), and the act of verbalisation itself may interfere with learning. To compensate for this limitation, the present study employed eye-tracking as an objective method to capture students' cognitive processing during task performance (van Gog et al., 2009), thereby providing empirical evidence for the benefits of embedding perspective-taking supports in illustrations. In addition, the relatively small sample size reflects the practical limitations of applying eye-tracking methodology with elementary school students, which restricts the generalisability of the findings. Moreover, as the study focused exclusively on Korean students, the cultural specificity of the context may limit the applicability of the results to other populations. Future research should therefore include larger and more diverse samples and conduct cross-cultural comparisons to further validate and extend these findings.

Conclusions and Implications

This study examined the effectiveness of embedding a perspective-taking support element to assist students in learning the causes of seasonal changes. Eye-tracking methodology was employed to investigate visual attention, gaze transitions between illustrations and text, and conceptual understanding. The findings provide clear

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evidence of the effectiveness of the perspective-taking support element, demonstrating its impact on students' cognitive processing.

The results showed that although there was no significant difference in overall visual attention to the key areas of the illustration, significant effects were observed in the number of gaze transitions between critical visual elements and in fixation durations on specific text segments. In terms of gaze transition patterns, the experimental group exhibited cyclical shifts between key sentences and corresponding illustrations, reflecting active integration of information. By contrast, the control group employed a more linear and less efficient strategy, processing the text first and only then attending to the illustration. These results indicate that the perspective-taking support helped students map related elements more effectively, thereby facilitating smoother and more efficient task performance. Furthermore, although the groups did not differ in pre-test conceptual understanding, the experimental group scored significantly higher on the post-test, indicating the educational effectiveness of the support in facilitating students' construction of scientific explanations.

Taken together, the findings provide empirical evidence that incorporating perspective-taking support elements leads to qualitatively different cognitive processing during science learning tasks. These supports facilitated students' comprehension of the illustrations, enabled more effective integration of visual and textual information, and helped them construct coherent mental models. The results underscore the importance of visual design strategies that naturally elicit perspective-taking-especially in tasks requiring spatial reasoning. Moreover, eye-tracking proved to be a powerful tool for gaining insights into how students process visual information, offering practical implications for the development of future educational materials in science education. Future research could extend these findings by exploring how perspective-taking supports influence student understanding of other space-related concepts-such as lunar phases or the Sun's apparent motion due to Earth's rotation—thus broadening the generalizability of this approach.

Conflict of Interest

The author(s) declared no conflicts of interest.

Acknowledgements

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Appendix

English Translation of Korean Text in Figure 2

"Seasonal changes occur because the Earth revolves around the Sun while its rotational axis is tilted. Due to this tilt, the Sun's altitude at noon varies depending on the Earth's position in its orbit, resulting in differences in the amount of solar energy received per unit area on the Earth's surface. These variations cause the seasons to change.

If the Earth's rotational axis were not tilted or if the Earth did not revolve around the Sun, seasonal changes would not occur."

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